GMI High Frequency Antenna Pattern Correction Update based on GPM Inertial Hold and Comparison with ATMS

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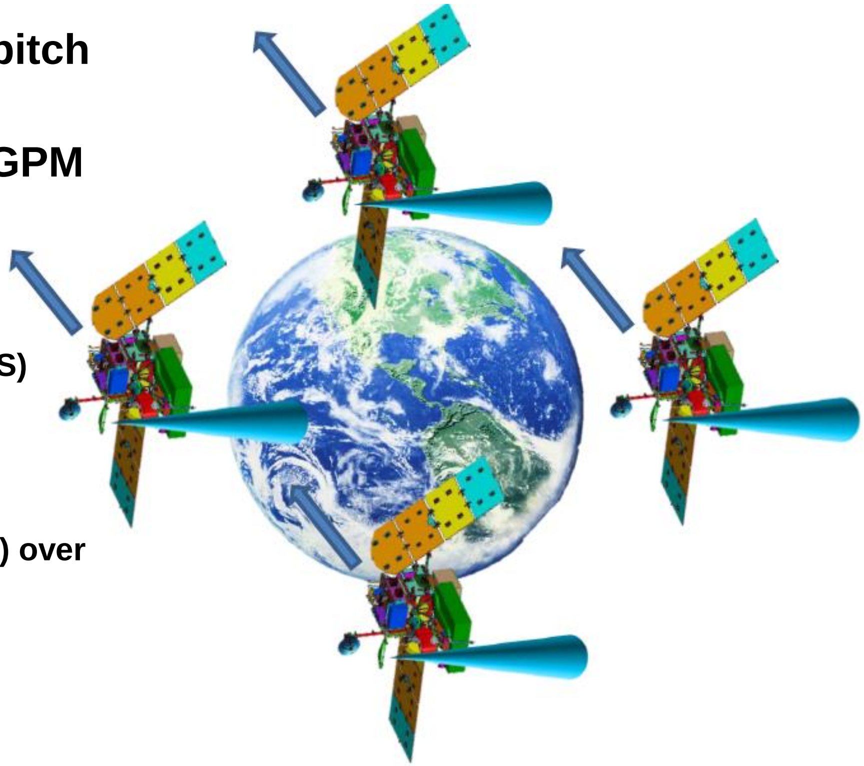
2-17-2015

"Inertial Hold" Affords Evaluation of the Antenna Pattern Correction

- In an inertial hold, the spacecraft does not attempt to maintain geodetic pointing, but rather maintains the same inertial position throughout the orbit
- The result is that the spacecraft appears to pitch from 0 to 360 degrees around the orbit
- Two inertial holds were performed with the GPM spacecraft
  - May 20, 2014 16:48:31 UTC – 18:21:04 UTC
    - Spacecraft flying forward +X (0° yaw)
    - Pitch from 55 degrees (FCS) to 415 degrees (FCS) over the orbit
  - Dec 9, 2014 01:30:00 UTC – 03:02:32 UTC
    - Spacecraft flying backward –X (180° yaw)
    - Pitch from 0 degrees (FCS) to 360 degrees (FCS) over the orbit
- The inertial hold affords a view of the earth through the antenna backlobe
- The antenna "spillover" correction may be evaluated based on the inertial hold data



Antenna Pattern Correction for 166V-pol and 166H-pol

- **The Antenna Pattern Correction for dual-polarization channels consists of 3 steps:**
  - **Spillover (η_v, η_h):**

$$\tilde{\tilde{T}}_{A,v} = \frac{1}{\eta_v} T_{A,v} - \frac{(1-\eta_v)}{\eta_v} T'_{cs}, \quad \tilde{\tilde{T}}_{A,h} = \frac{1}{\eta_h} T_{A,h} - \frac{(1-\eta_h)}{\eta_h} T'_{cs}$$

  - **Antenna Reflectivity (R):**

$$\tilde{T}_{A,v} = \frac{1}{R} \tilde{\tilde{T}}_{A,v} - \frac{(1-R)}{R} T_{refl}, \quad \tilde{T}_{A,h} = \frac{1}{R} \tilde{\tilde{T}}_{A,h} - \frac{(1-R)}{R} T_{refl}$$

  - **Cross-polarization (a_{vh}, a_{hv})**

$$\begin{pmatrix} T_{B,v} \\ T_{B,h} \end{pmatrix} = \frac{1}{1-a_{hv}-a_{vh}} \begin{pmatrix} 1-a_{hv} & -a_{vh} \\ -a_{hv} & 1-a_{vh} \end{pmatrix} \begin{pmatrix} \tilde{T}_{A,v} \\ \tilde{T}_{A,h} \end{pmatrix}$$

- **The spillover coefficients are currently set to “1”, meaning no correction is performed**

f [GHz]	10.65	18.7	23.8	36.64	89.0	166.0	183.31
a_{vh}	0.00363	0.00280	0.00211*	0.00094	0.00119	0.01339	0.01104*
a_{hv}	0.00366	0.00292	N/A	0.00094	0.00119	0.01339	N/A
η_v	0.94435	0.93968	0.96601*	0.99590	0.99810	1.00000	1.00000*
η_h	0.94369	0.94082	N/A	0.99590	0.99810	1.00000	N/A
$1-\eta_v$	0.05565	0.06032	0.03399*	0.00410	0.00190	0.00000	0.00000*
$1-\eta_h$	0.05631	0.05918	N/A	0.00410	0.00190	0.00000	N/A
λ	N/A	N/A	1.03386	N/A	N/A	N/A	1.00000
ξ	N/A	N/A	0.28259	N/A	N/A	N/A	0.00000
R	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

2344649 GMI Calibration Databook Rev F

Antenna Pattern Correction for 183.31±3 v-pol (VA) and 183.31±7 v-pol(VB)

- **The Antenna Pattern Correction for single-polarization channels is a simplified 2-step process:**
  - **Spillover/Cross-pol (λ, ξ):** $\tilde{\tilde{T}}_{A,v} = \lambda T_{A,v} + \xi, \quad \lambda \cong 1/\eta_v, \quad \xi \cong -[(1-\eta_v)/\eta_v]T'_{cs}$
  - **Antenna Reflectivity (R):** $T_{A,v} = \frac{1}{R}\tilde{\tilde{T}}_{A,v} - \frac{(1-R)}{R}T_{refl}$

- **The spillover coefficients are currently set to "1", meaning no correction is performed**

f [GHz]	10.65	18.7	23.8	36.64	89.0	166.0	183.31
a_{vh}	0.00363	0.00280	0.00211*	0.00094	0.00119	0.01339	0.01104*
a_{hv}	0.00366	0.00292	N/A	0.00094	0.00119	0.01339	N/A
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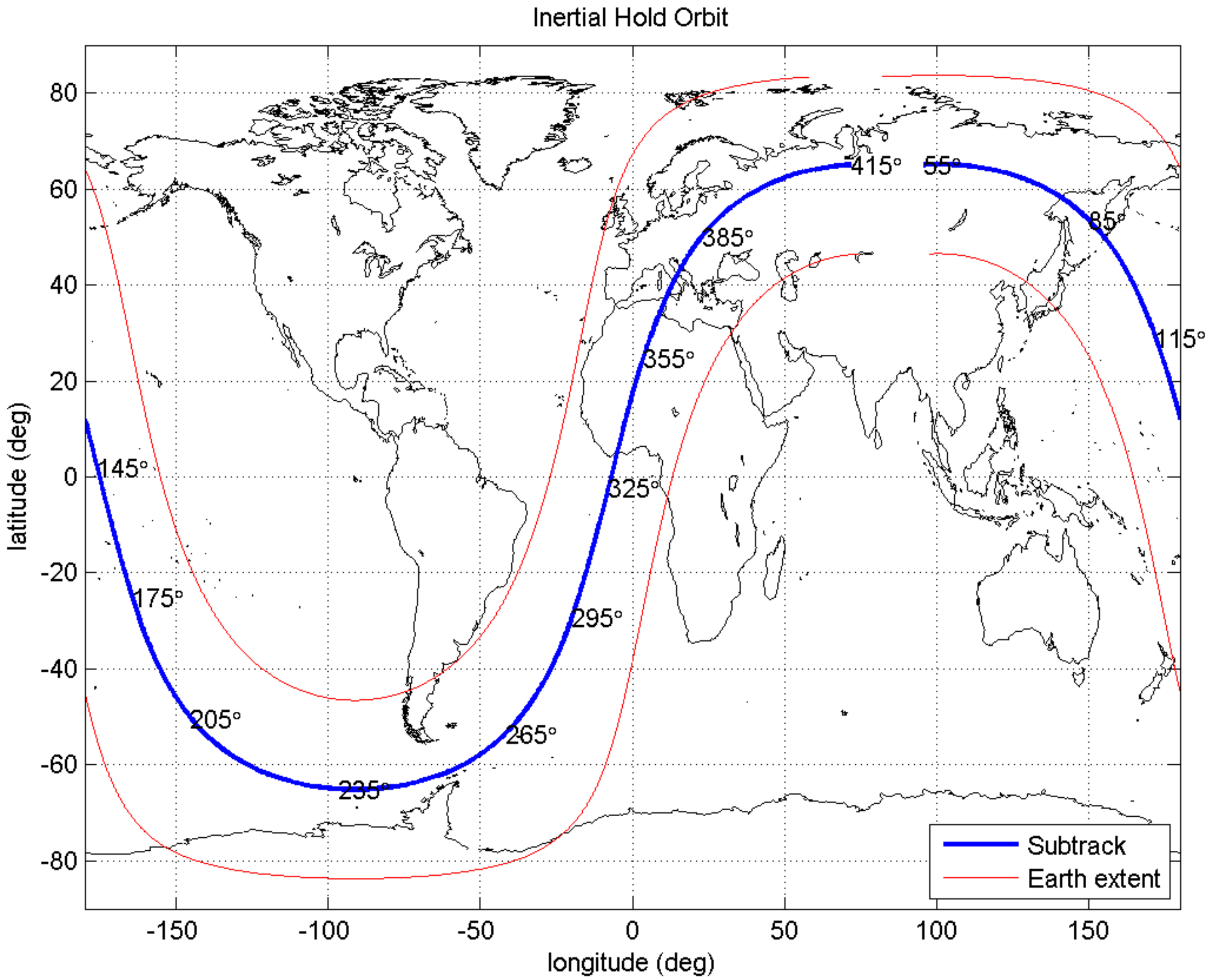
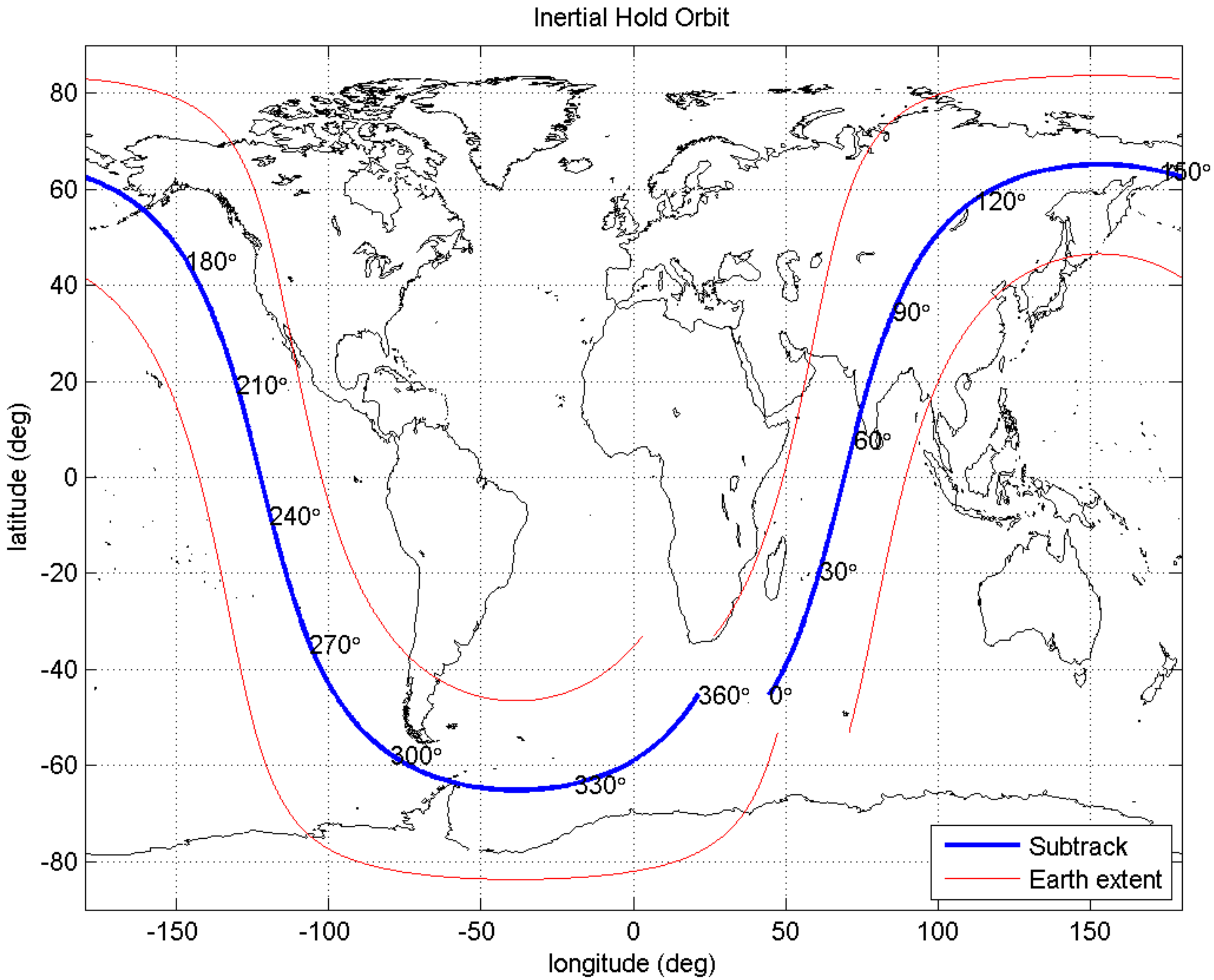
$1-\eta_v$	0.05565	0.06032	0.03399*	0.00410	0.00190	0.00000	0.00000*
$1-\eta_h$	0.05631	0.05918	N/A	0.00410	0.00190	0.00000	N/A
λ	N/A	N/A	1.03386	N/A	N/A	N/A	1.00000
ξ	N/A	N/A	0.28259	N/A	N/A	N/A	0.00000
R	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

2344649 GMI Calibration Databook Rev F

Inertial Hold #1 Orbit



Inertial Hold #2 Orbit



Inertial Hold #1 Raw Data shows earth intrusion into the Cold View

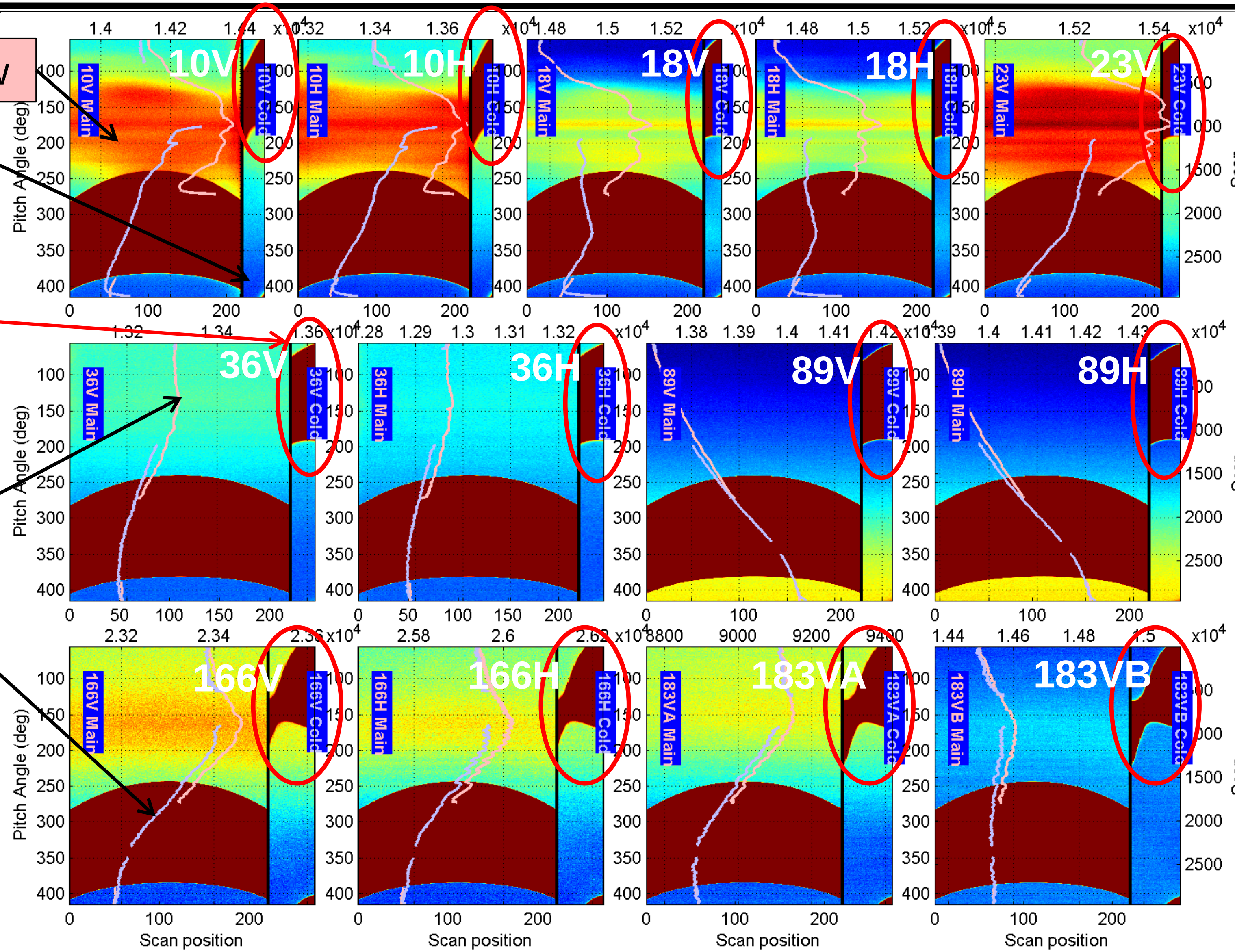
Main Beam View

Cold View

Cold View Intrusion

Main Beam Average

Cold View Average



(Color Scale Set to just show cold space data)

Inertial Hold #2 Raw Data also shows earth intrusion into the Cold View

Main Beam View

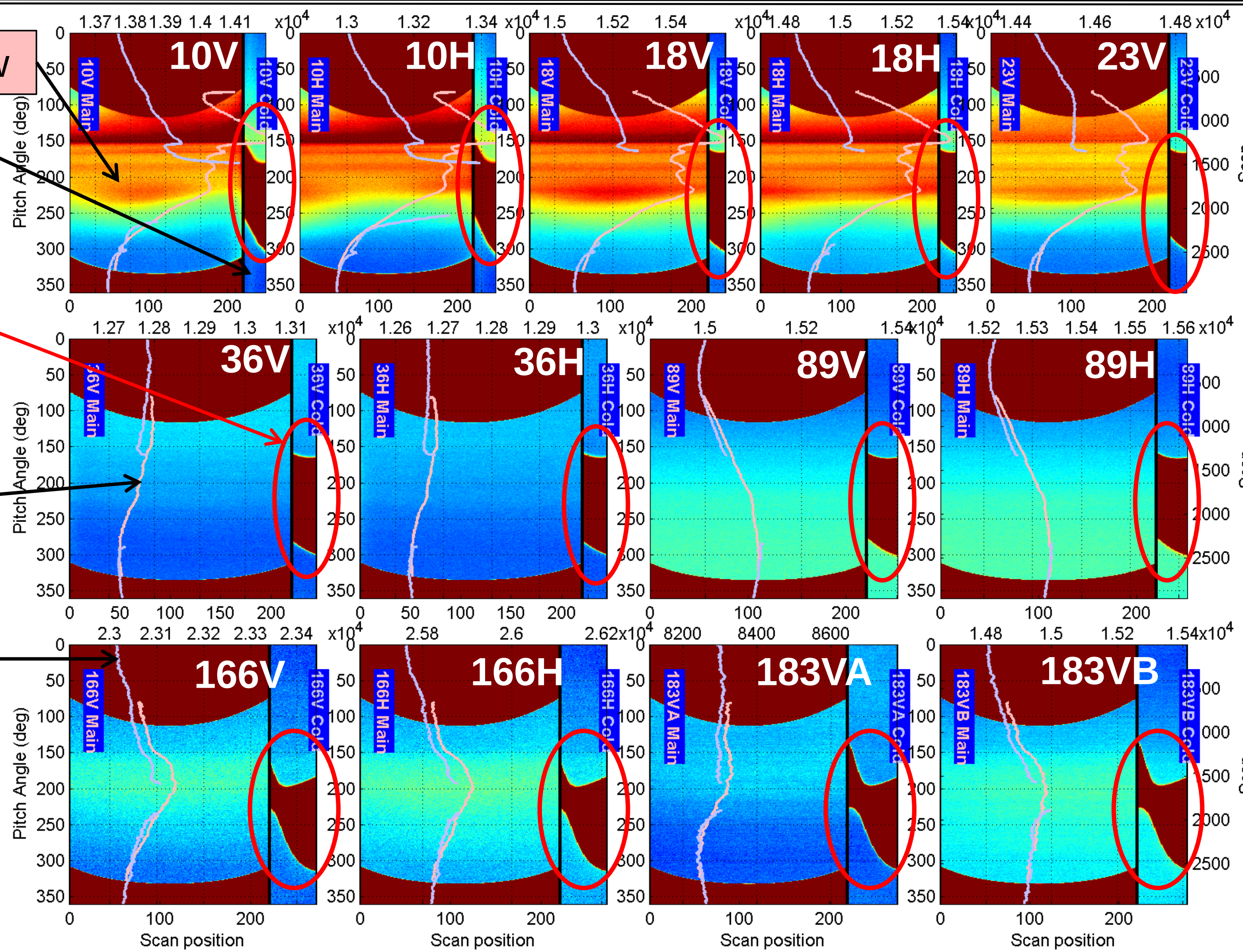
Cold View

Cold View Intrusion

Main Beam Average

Cold View Average

(Color Scale Set to just show cold space data)

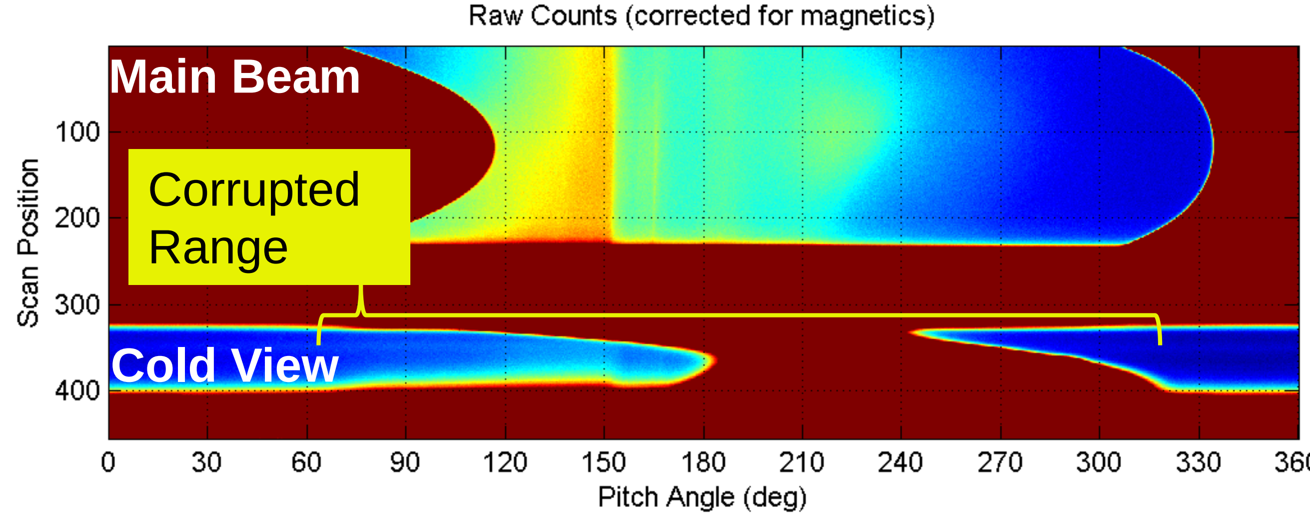


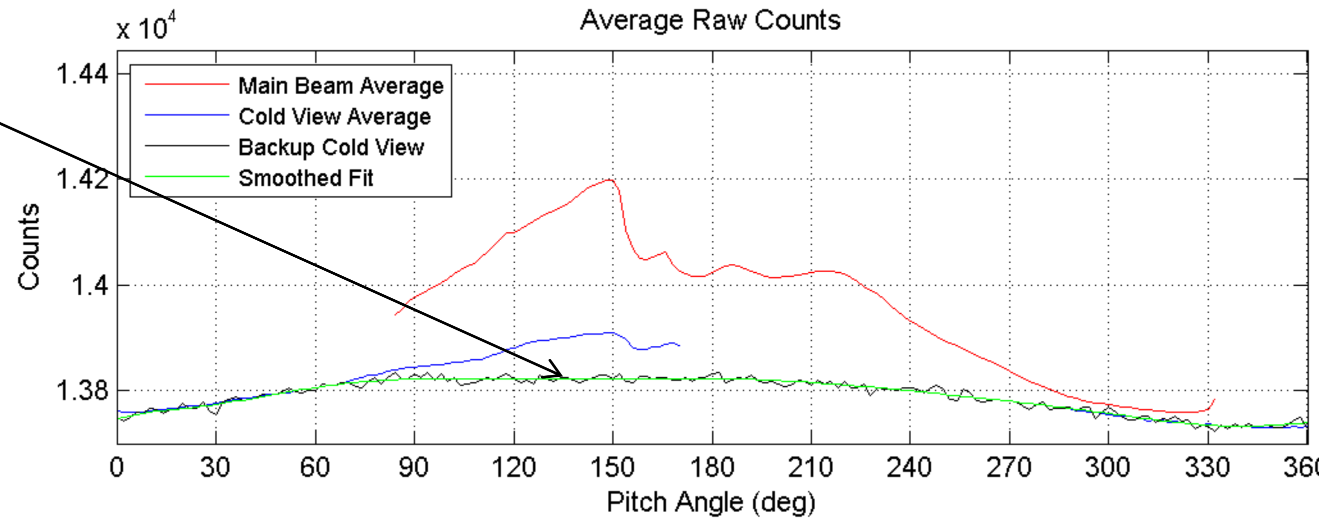
Cold view earth intrusion may be removed

- **The cold view temperature can be estimated in the following ways:**
  - **Using backup calibration with Hot and Hot+Noise**
    - **An offset is added to account for possible drift in the noise diode**
    - **Applies to 10, 18, 23, 36 GHz**
  - **Fitting the uncorrupted portion of the data with the receiver temperature and using the fit to fill in the data that is corrupted**
    - **Works well with 89 GHz**
  - **Using One-point calibration (using the Hot Load and gain look-up table as a function of temperature)**
    - **The one-point cal data is "not exact", but the shape of the estimated cold cal data (from one-point cal) can be fit to the uncorrupted portion and used to fill in data that is corrupted**
    - **Works well with 166 GHz and 183 GHz**

Example of Estimating the Cold View Temperature using Backup Cal (10V)

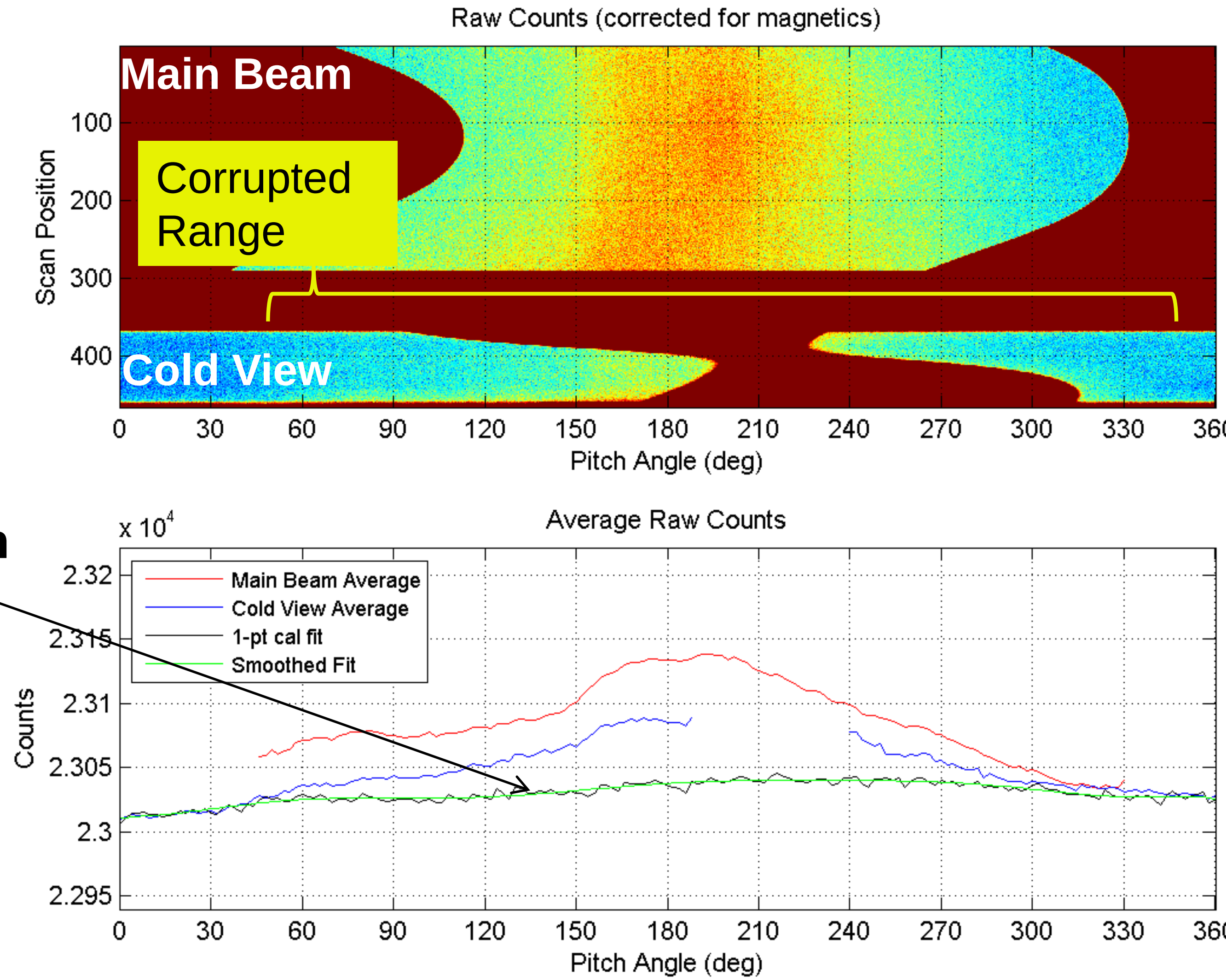
- **Plot Shows the Raw 10V inertial hold data (entire scan)**
- **The backup cal is used to estimate the cold temperature over the portion corrupted by earth**





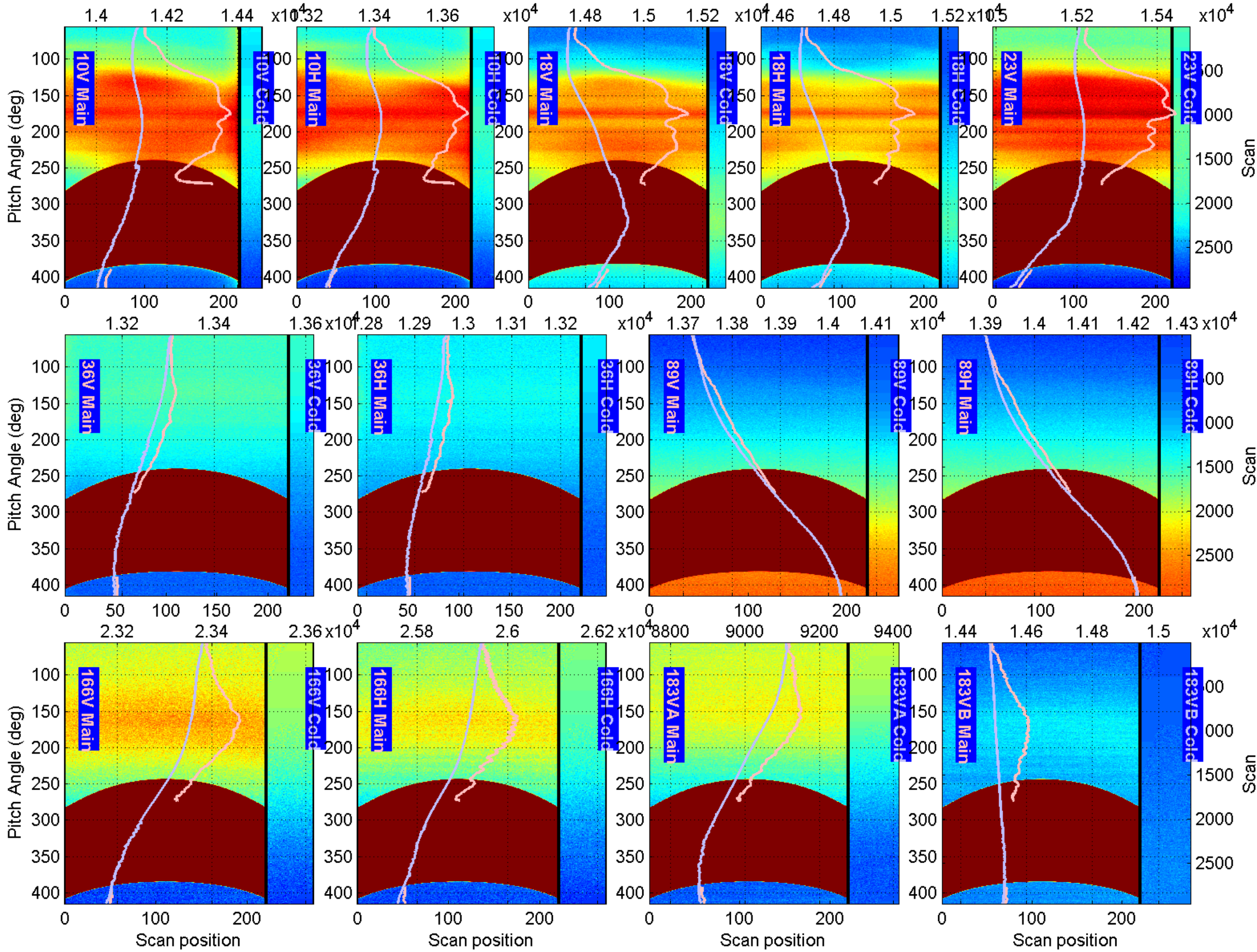
Example of Estimating the Cold View Temperature using 1-point Cal (166V)

- Plot Shows the Raw 10V inertial hold data (entire scan)
- The 1-point cal is used to estimate the cold temperature over the portion corrupted by earth



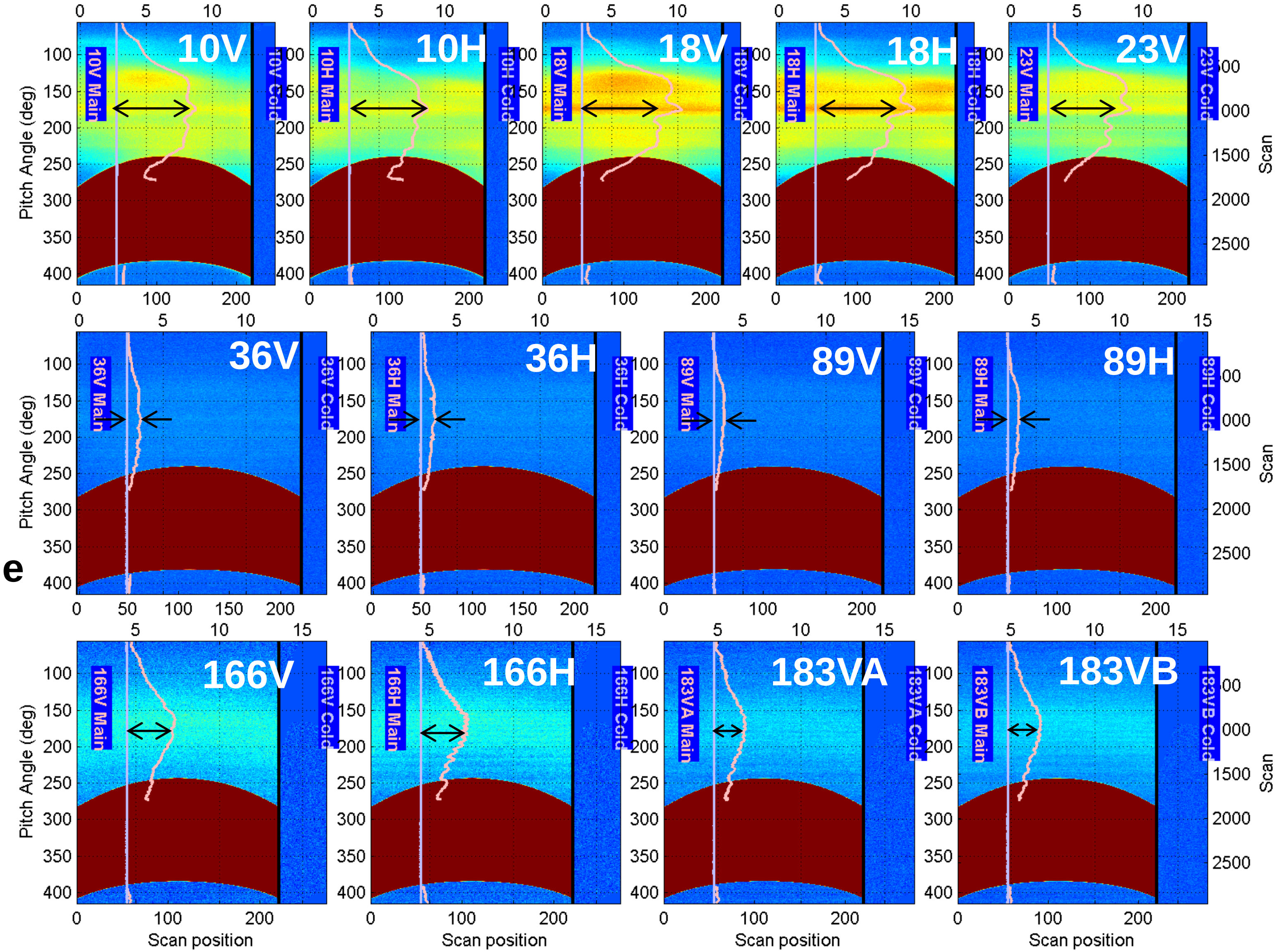
Inertial Hold #1 After Repairing Cold View

- **Cold View has been Repaired by filling in or adjusting values in the corrupted range**



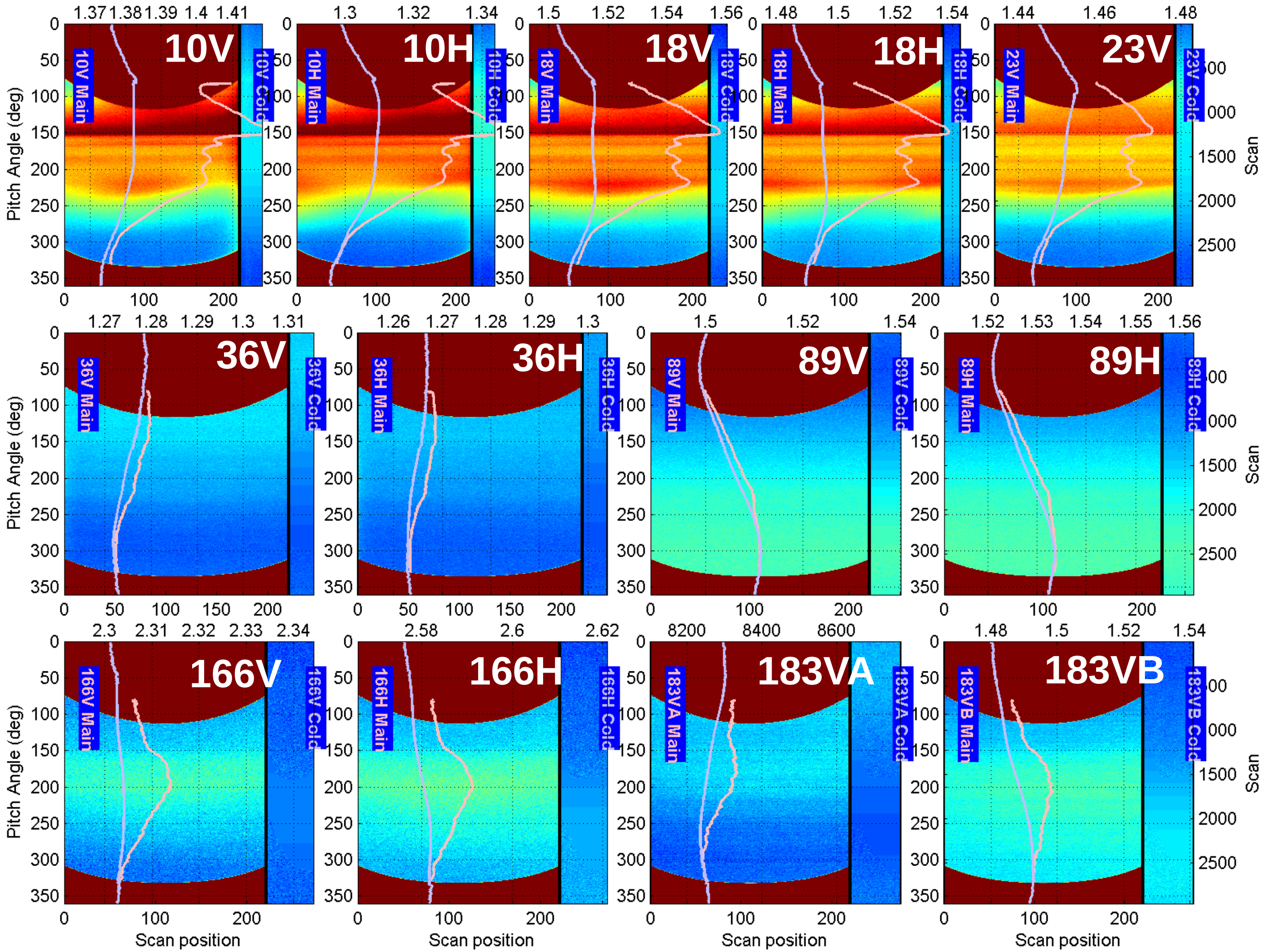
After calibrating to get TA, the earth intrusion coming through the GMI backlobe is evident

- **The difference between the cold and main beam views is caused from the earth coming through the GMI backlobe/side lobes.**



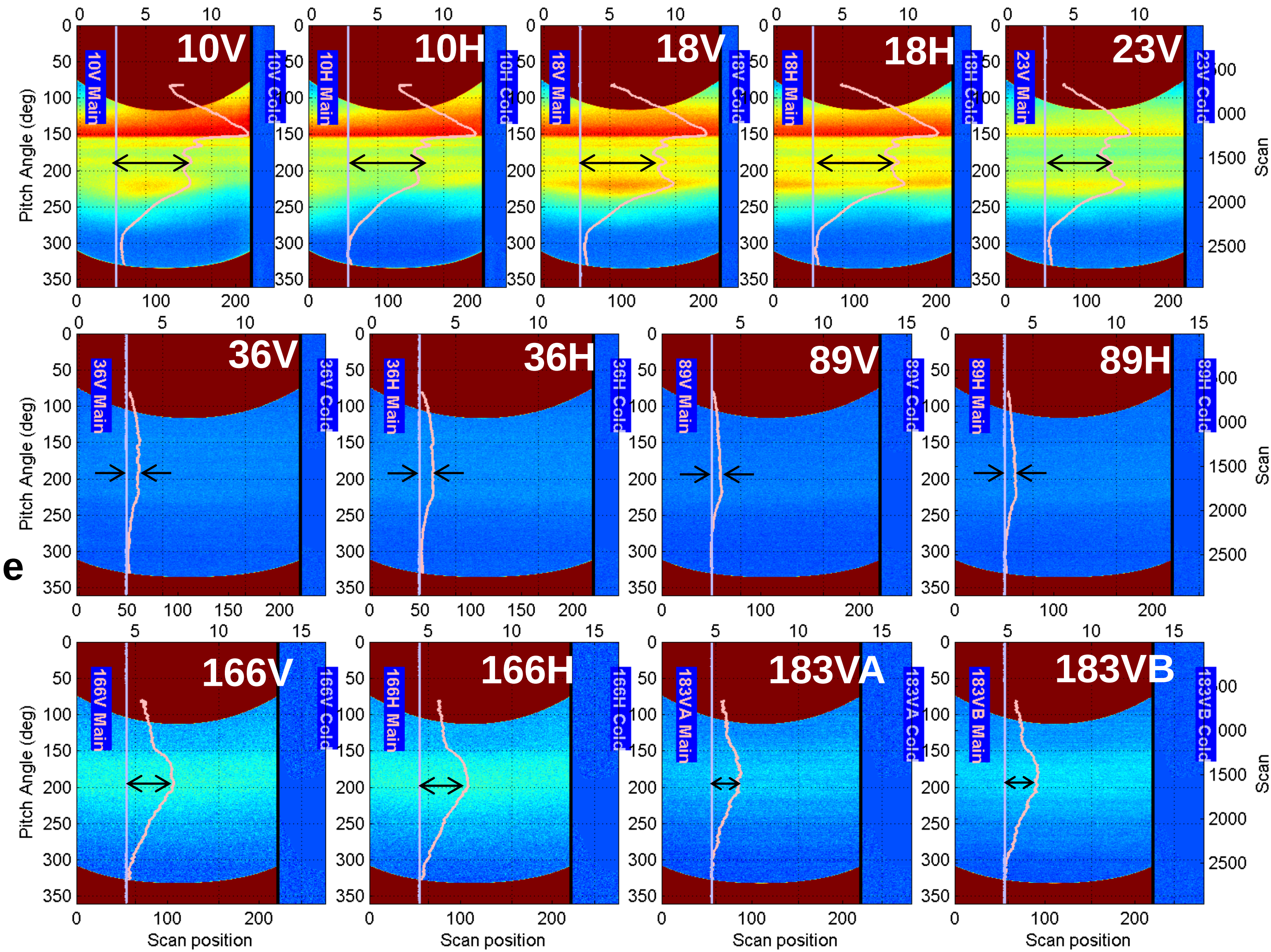
Inertial Hold #2 After Repairing Cold View

- Cold View has been Repaired by filling in or adjusting values in the corrupted range



After calibrating to get TA, the earth intrusion coming through the GMI backlobe is evident

- The difference between the cold and main beam views is caused from the earth coming through the GMI backlobe/side lobes.



Estimating the Antenna Spillover from the inertial hold data

- **When the spacecraft is "upside down", the antenna temperature can be approximated as,**

$$T_{A-upsidedown} = \eta T'_{cs} + (1-\eta) T_{b-earth}.$$

- **Solving for the spillover coefficient, we get**

$$\boxed{\eta = (T_{b-earth} - T_{A-upsidedown}) / (T_{b-earth} - T'_{cs})}$$

- **The** $T_{A\text{–}upsidedown}$ **is the measured TA from the inertial hold data**
- **The** $T_{b\text{–}earth}$ **is the brightness temperature of the earth at the earth incidence angle of the backlobe**
- **We have verified that the error due to the Rayleigh-Jeans law approximation is negligible.**

Estimating the Earth Brightness Temperature in the Backlobe $T_{b\text{-}earth}$ (1/3)

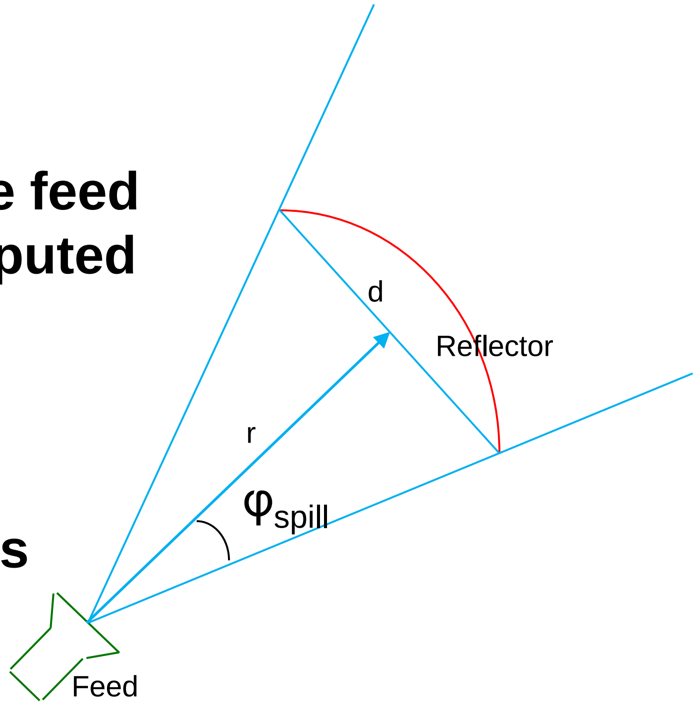
- **The incidence angle of the earth for the GMI backlobe while the GPM spacecraft is "upside down" can be estimated from the geometry of the feeds and reflector**
  - **The angle of energy spilling around the reflector φ_{spill} can be written as**

$$\varphi_{spill} = \tan^{-1}\left(\frac{d/2}{r}\right)$$

  - **The earth incidence angle, assuming the feed is pointed toward geodetic nadir is computed as**

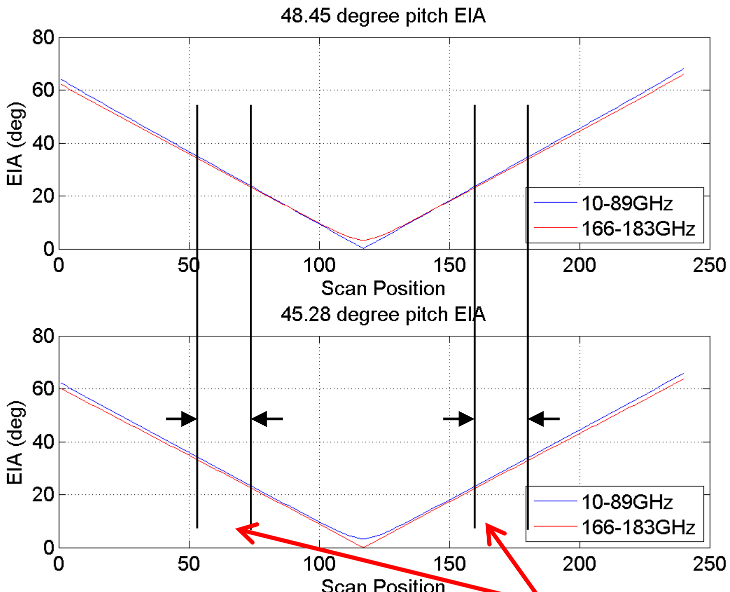
$$EIA_{spill} = \sin^{-1}\left[\frac{h+re}{re}\sin\left(\varphi_{spill}\right)\right]$$

  - **where h is the altitude, re the earth radius**



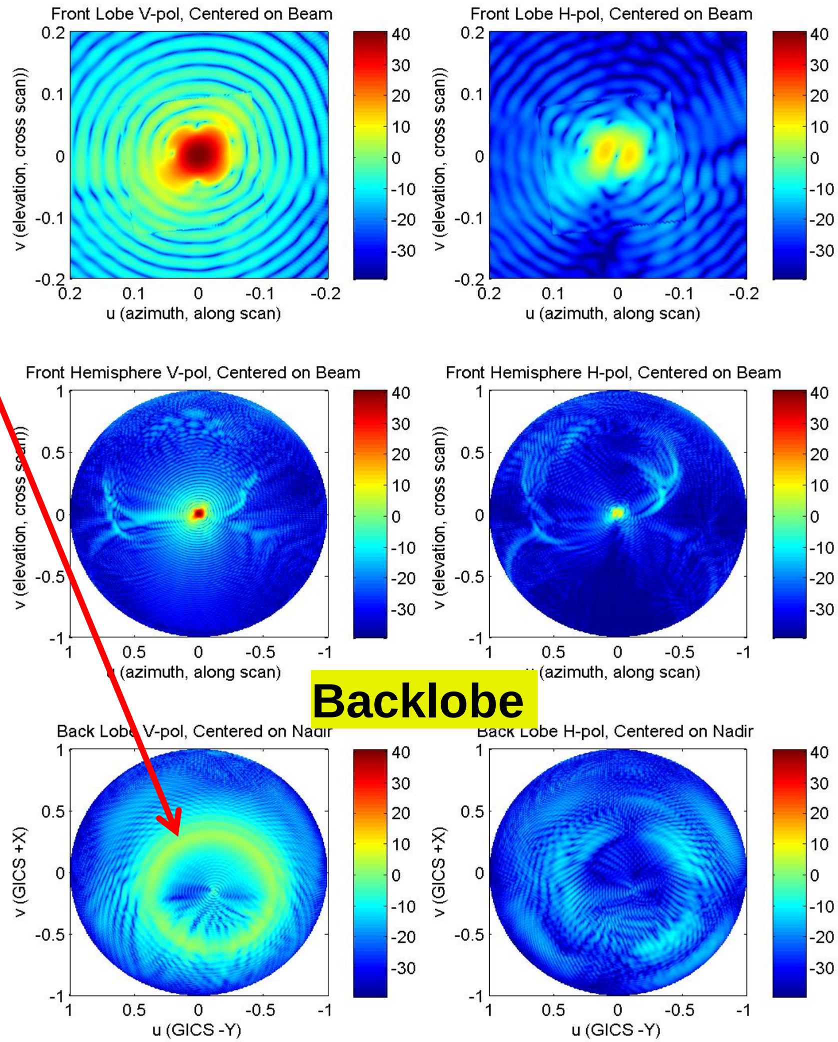
Estimating the Earth Brightness Temperature in the Backlobe $T_{b\text{-}earth}$ (2/3)

- **For GMI, φ_{spill} is 20.8 degrees, and EIA_{spill} is 22.3 degrees**
- **The spillover occurs over at least a 10 degree range around the reflector edge**
- **GMI data at these earth incidence angles is available during the special "nadir-viewing" pitch maneuvers on December 8th, 2014:**



EIA Range Required to determine Tb-earth

10 V Pattern

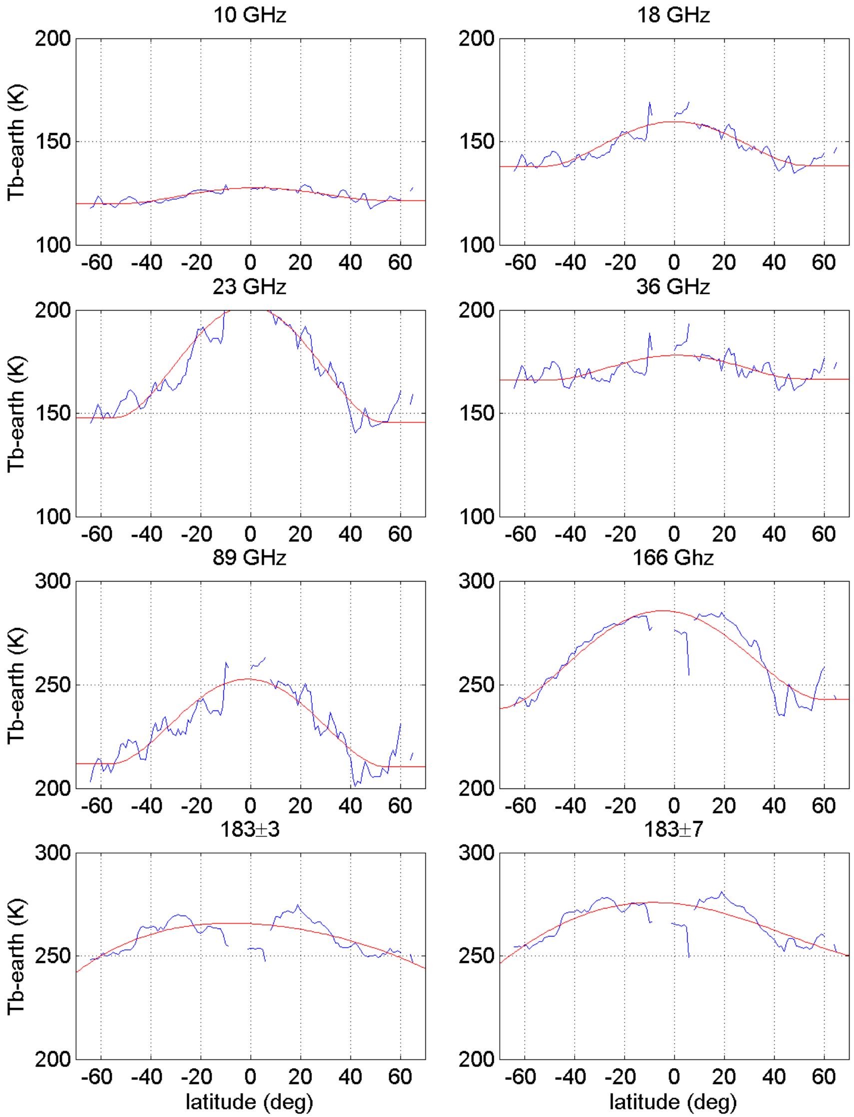


Estimating the Earth Brightness Temperature in the Backlobe $T_{b\text{-}earth}$ (3/3)

- **The $T_{b\text{-}earth}$ values computed from the nadir-looking orbits are shown to the right**
  - **Averaged for EIA 22° to 33°**
    - **Approximate range of the backlobe ring**
  - **Averaged for V and H pol**
    - **The backlobe contribution represents a combination of v and h since it is a ring about the center of the feed beam**
- **Data below show the $T_{b\text{-}earth}$ values for the latitudes when the spacecraft is pitched to where the feed pointing is nadir-looking (maximum backlobe)**

freq (GHz)	Inertial Hold 1			Inertial Hold 2		
	pitch*	lat	Tb-earth	pitch*	lat	Tb-earth
10.65	168.8	-19.5063	126.2	191.2	35.8	124.2
18.7	171.9	-22.2953	150.7	188.1	38.5	142.3
23.8	171.9	-22.2955	181.9	188.1	38.5	155.1
36.64	172.1	-22.4591	171.0	187.9	38.6	168.8
89	172.8	-23.0969	234.5	187.2	39.2	214.4
166	171.4	-21.8316	279.8	188.6	38.0	250.3
183.31±3	171.4	-21.8305	264.5	188.6	38.0	255.0
183.31±7	171.4	-21.8305	274.2	188.6	38.0	259.2

* Corresponds to Feed Pointing to within 10 degrees of nadir



Estimated Spillover

- **Using the inertial hold data the estimated spillover is given below as computed using the following equation:**

$$\eta = (T_{b-earth} - T_{A-upsidedown}) / (T_{b-earth} - T'_{cs})$$

- **The effective error in the current (Rev "F") correction to that measured during the inertial hold "IH" is approximated:**

$$\Delta Tb = \left[(1/\eta_F) - (1/\eta_{IH})\right] T_{A-ocean}$$

Channel	Inertial Hold # 1 (IH1)				Inertial Hold # 2 (IH2)				Average of IH1 and IH2 (η_{IH})	Cal Data book F (η_F)	Proposed Cal Data Book G (η_G)	ΔTb over ocean
	Tb-earth	TA-upside down	Tcs'	η	Tb-earth	TA-upside down	Tcs'	η				
10V	126.2	8.6	2.74	0.95252	124.2	8.3	2.74	0.95389	0.95320	0.94435		1.6
10H	126.2	8.4	2.74	0.95412	124.2	8.1	2.74	0.95566	0.95489	0.94369		1.1
18V	150.7	10.0	2.75	0.95103	142.3	9.1	2.75	0.95465	0.95284	0.93968		2.6
18H	150.7	10.0	2.75	0.95122	142.3	9.1	2.75	0.95478	0.95300	0.94082		1.6
23V	181.9	8.8	2.77	0.96652	155.1	7.7	2.77	0.96743	0.96697	0.96601		0.2
36V	171.0	3.6	2.82	0.99517	168.8	3.6	2.82	0.99551	0.99534	0.99590		-0.1
36H	171.0	3.7	2.82	0.99492	168.8	3.6	2.82	0.99505	0.99499	0.99590		-0.1
89V	234.5	3.9	3.27	0.99742	214.4	3.8	3.27	0.99761	0.99751	0.99810		-0.2
89H	234.5	3.9	3.27	0.99717	214.4	3.9	3.27	0.99705	0.99711	0.99810		-0.2
166V	279.8	7.3	4.43	0.98969	250.3	7.2	4.43	0.98857	0.98913	1.00000	0.9891*	-2.9
166H	279.8	7.2	4.43	0.99003	250.3	7.4	4.43	0.98805	0.98904	1.00000	0.9891*	-2.9
183VA	264.5	6.6	4.76	0.99276	255.0	6.4	4.76	0.99344	0.99310	1.00000	0.9928*	-1.8
183VB	274.2	6.7	4.76	0.99266	259.2	6.7	4.76	0.99222	0.99244	1.00000	0.9928*	-2.0

* Average of the two channels of the same frequency

Proposed Update to Cal Databook

- **It is proposed to update the calibration databook:**

WAS (Rev F)

f [GHz]	10.65	18.7	23.8	36.64	89.0	166.0	183.31
a_{vh}	0.00363	0.00280	0.00211*	0.00094	0.00119	0.01339	0.01104*
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$1-\eta_h$	0.05631	0.05918	N/A	0.00410	0.00190	0.00000	N/A
λ	N/A	N/A	1.03386	N/A	N/A	N/A	1.00000
ξ	N/A	N/A	0.28259	N/A	N/A	N/A	0.00000
R	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

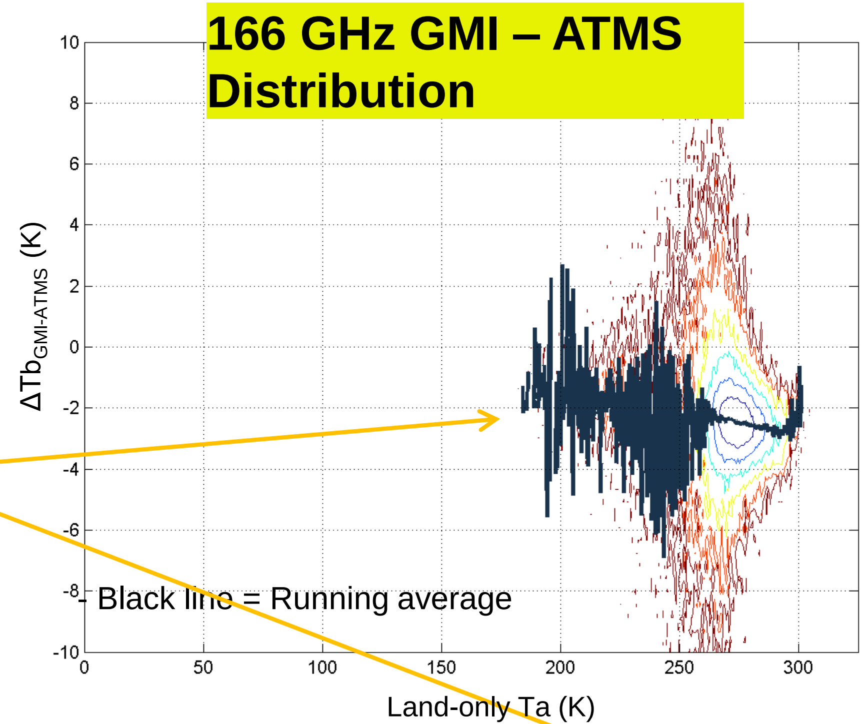
IS (Rev G)

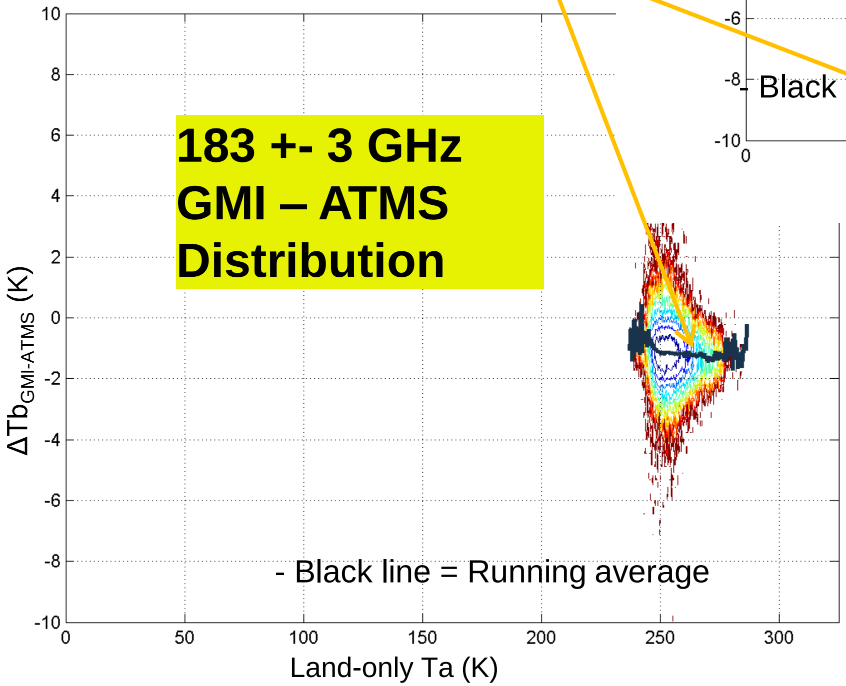
GHz]	10.65	18.7	23.8	36.64	89	166	183.31
	0.00363	0.0028	0.00211	0.00094	0.00119	0.01339	0.01104
a_{hv}	0.00366	0.00292	N/A	0.00094	0.00119	0.01339	N/A
η_v	0.94435	0.93968	0.96601	0.9959	0.9981	**0.9891**	**0.9928**
η_h	0.94369	**0.93922**	N/A	0.9959	0.9981	**0.9891**	N/A
$1-\eta_v$	0.05565	0.06032	0.03399	0.0041	0.0019	**0.0109**	**0.0072**
$1-\eta_h$	0.05631	**0.06078**	N/A	0.0041	0.0019	**0.0109**	N/A
λ	N/A	N/A	1.03386	N/A	N/A	N/A	**1.0073**
ξ	N/A	N/A	0.28259	N/A	N/A	N/A	**-0.03**
R	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

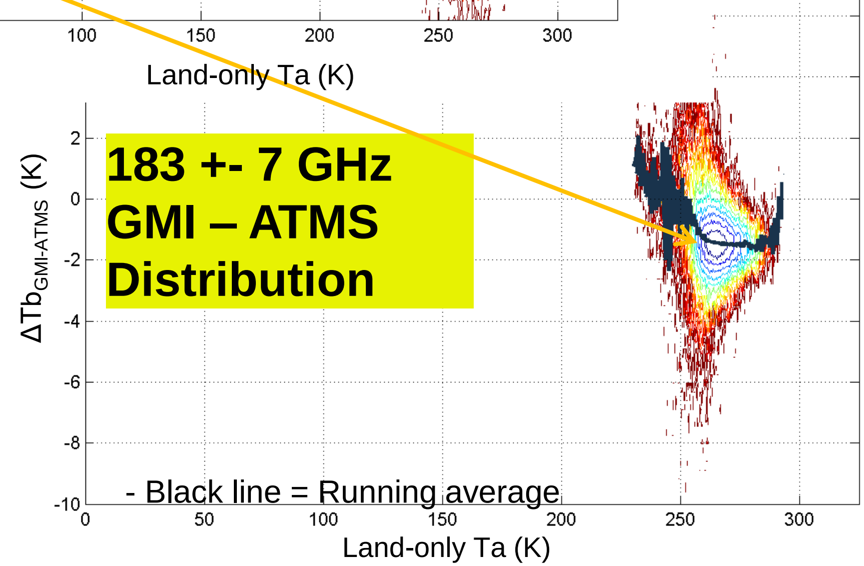
166 and 183 Comparison to ATMS (over land)

- **Before Spillover Correction**

Slant is indicative of a spill-over (multiplicative) error in GMI data



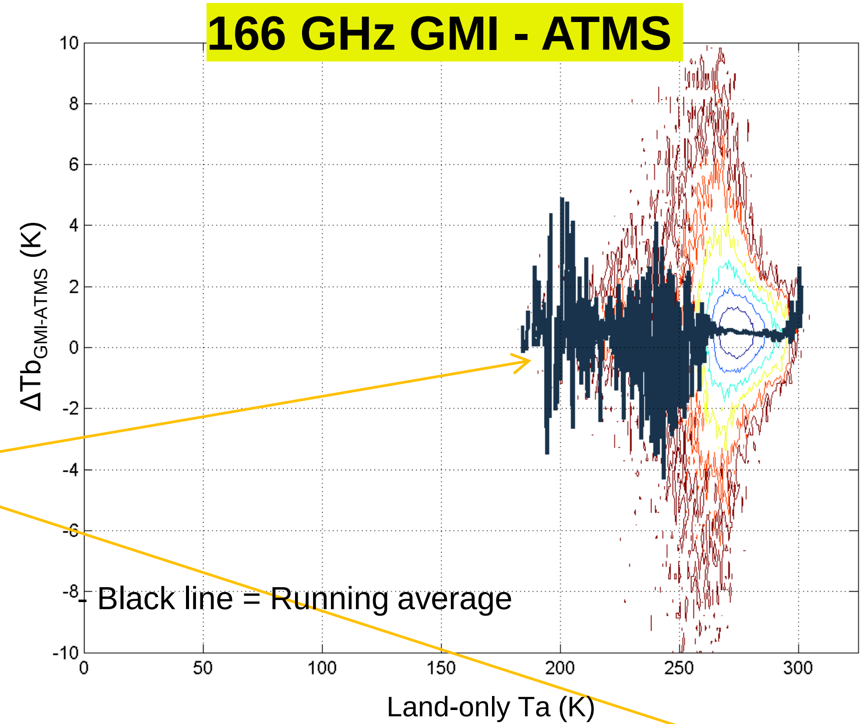


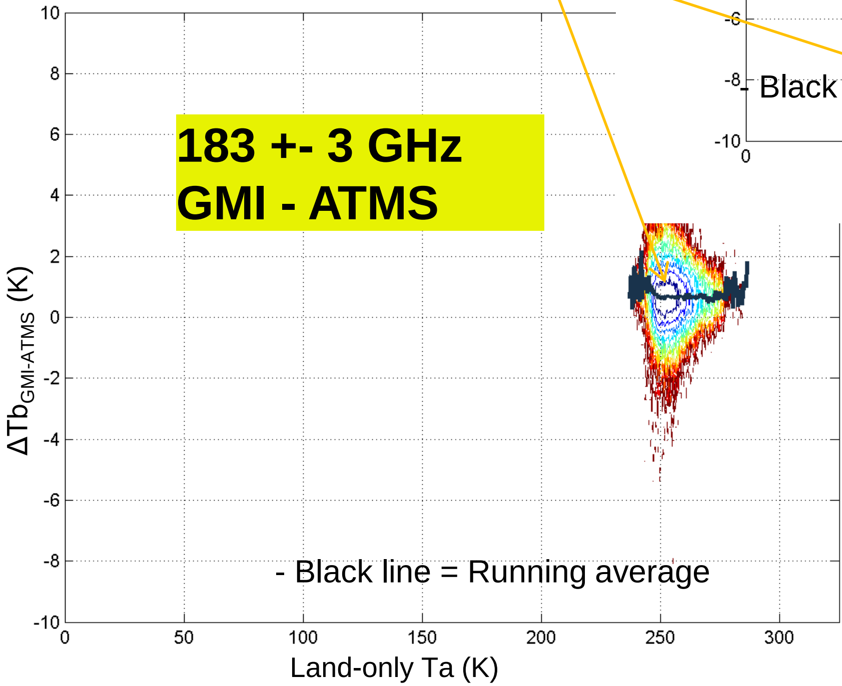


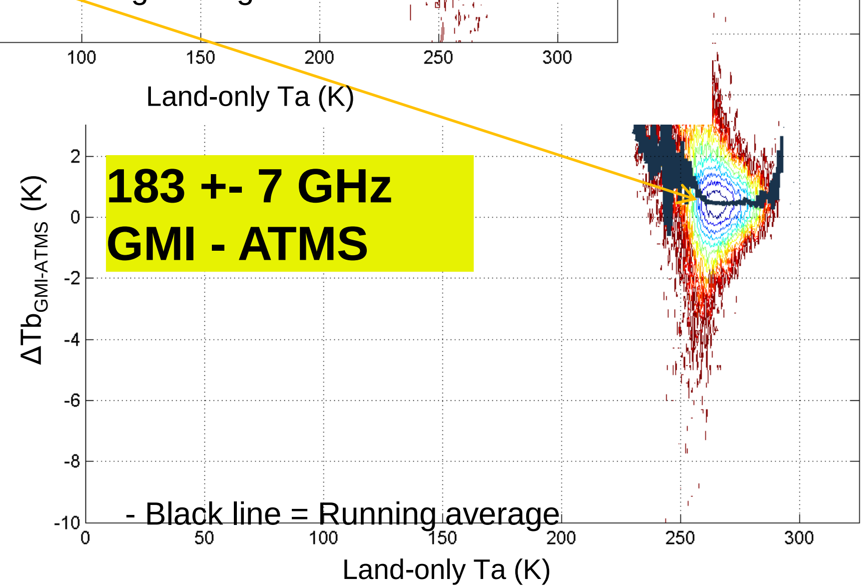
166 and 183 Comparison to ATMS (over land)

- **After Spillover Correction**

Slant Essentially Disappears







GMI to ATMS Error (over land)

- **The GMI to ATMS error over land near the "mode" of the distribution is given below**
  - **Data near the mode of the distribution is less sensitive to surface polarization effects**
- **The spillover correction changes the sizeable negative GMI to ATMS difference into a small positive bias**

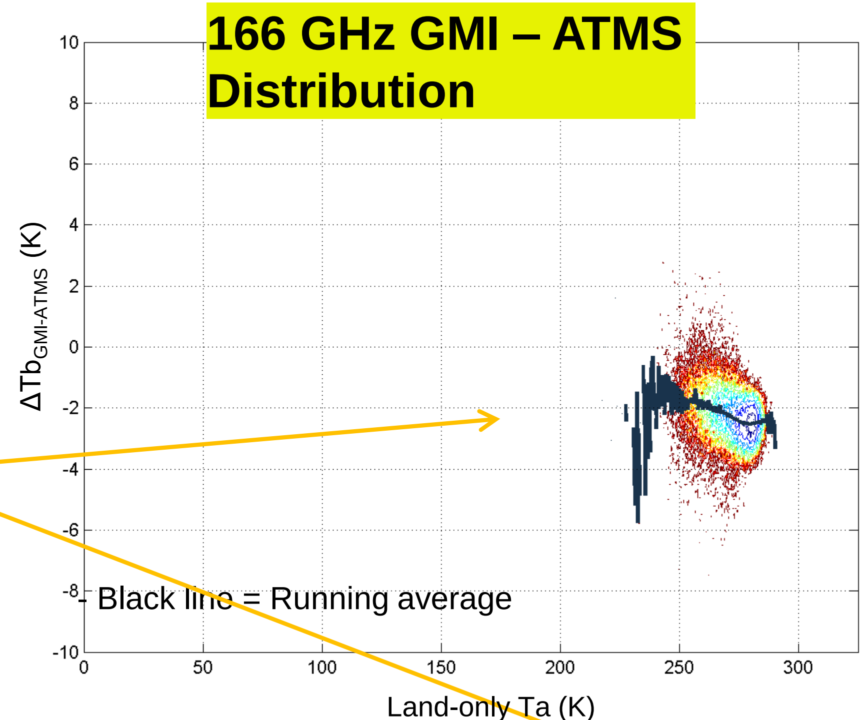
GMI – ATMS Difference

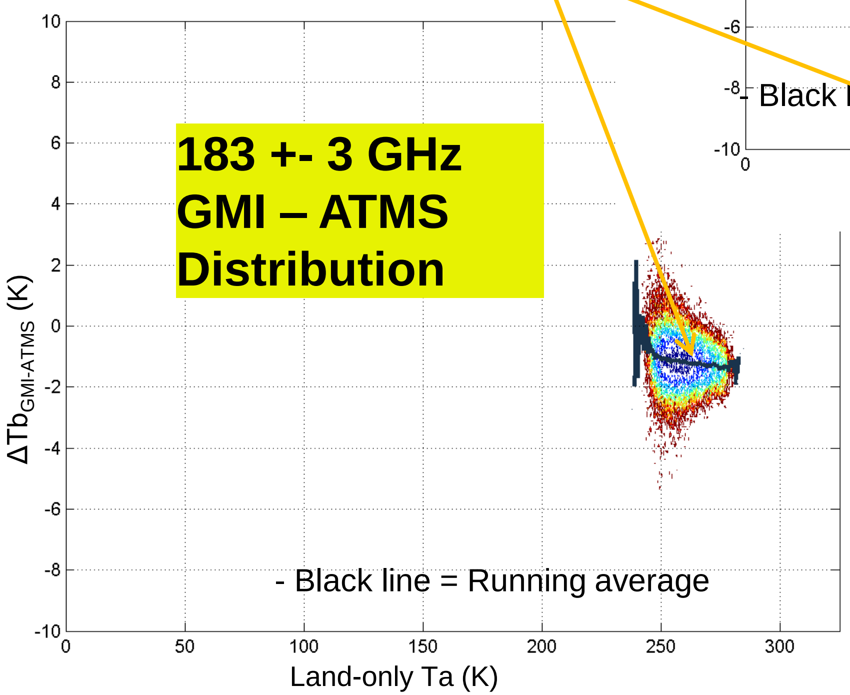
Frequency (GHz)	Before Spillover Correction	After Spillover Correction	Delta (Before – After)
183 ± 3	-1.1K	0.7K	-1.8K
183 ± 7	-1.4K	0.5K	-1.9K
166	-2.4K	0.5K	-2.9K

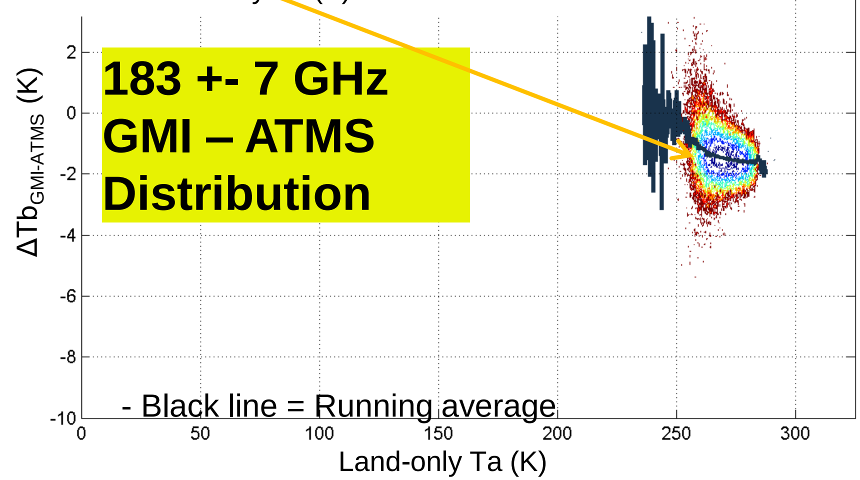
166 and 183 Comparison to ATMS (over ocean)

- **Before Spillover Correction**

Slant evident in the ocean data



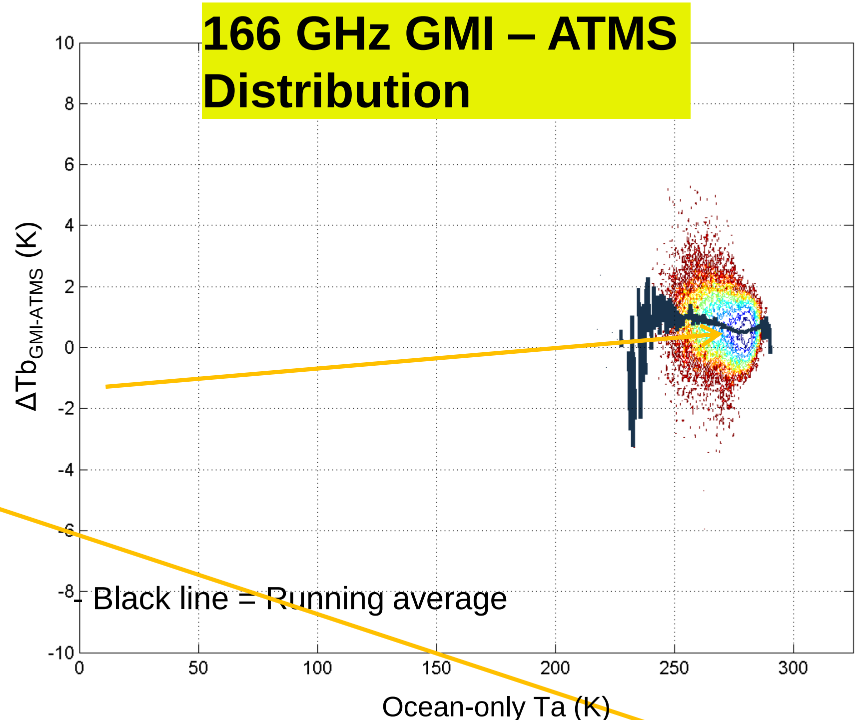


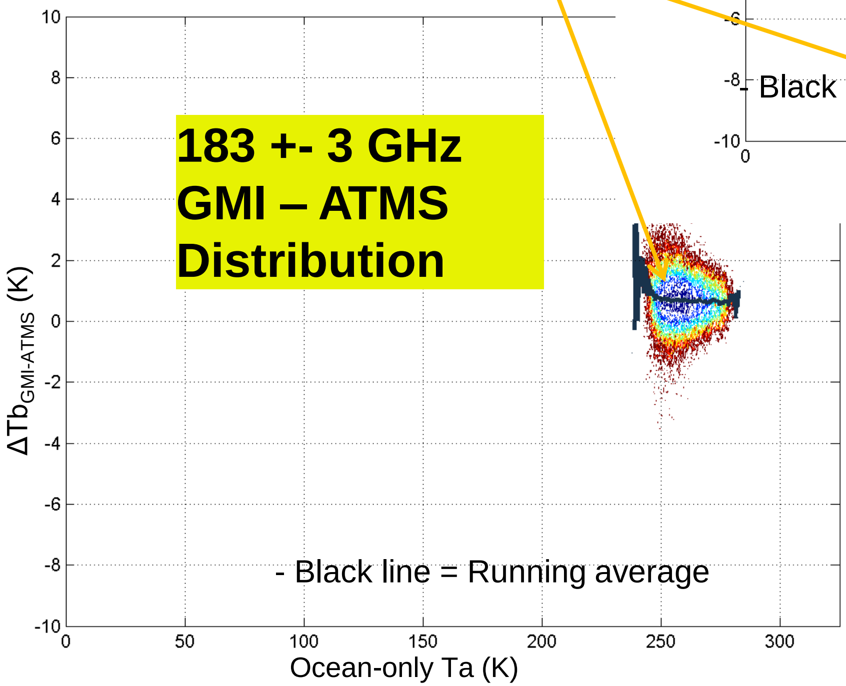


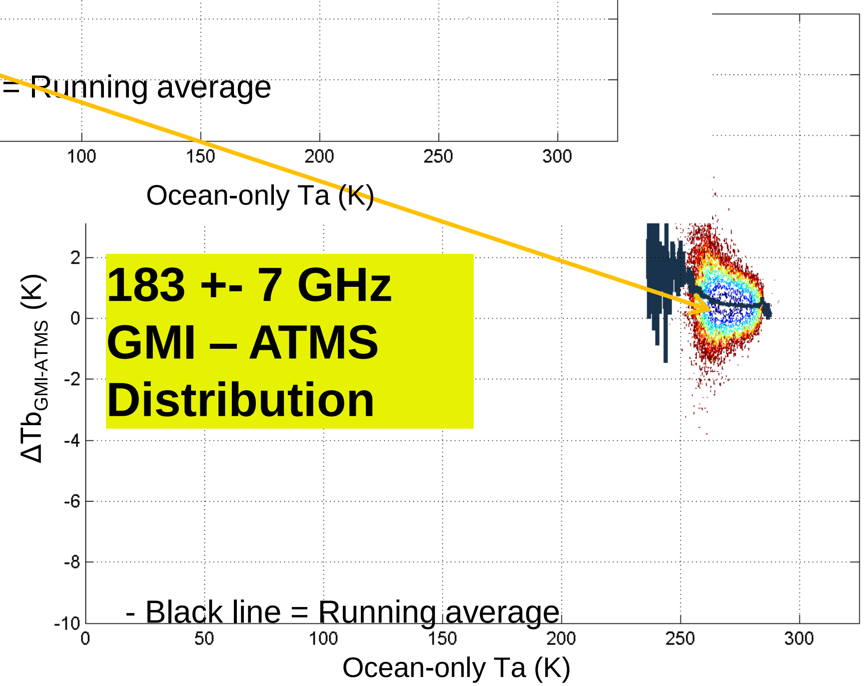
166 and 183 Comparison to ATMS (over ocean)

- **After Spillover Correction**

Slant reduced with spill-over correction







GMI to ATMS Error (over ocean)

- **The GMI to ATMS error over land near the “mode” of the distribution is given below**
- **The ocean delta is very similar to the land delta.**

GMI – ATMS Difference

Frequency (GHz)	Before Spillover Correction	After Spillover Correction	Delta (Before – After)
183 ± 3	-1.1K	0.7K	-1.8K
183 ± 7	-1.4K	0.5K	-1.9K
166	-2.3K	0.6K	-2.9K

An Interesting Curiosity: Spillover Difference in 10 and 18 GHz

- **One note from this analysis is that the computed 10 and 18 GHz spillover coefficient is different by about 1% compared to the ground-measured spillover**
- **It is not completely clear why the difference exists, although it is plausible that it is partially due to the High Gain Antenna in the GMI backlobe blocking a portion of the earth radiation when upside down.**
  - **The blockage would need to represent about 30% of the backlobe in order to explain the difference**
  - **The error in the low frequencies give a good upper bound of about 30% for the uncertainty of the inertial hold data to predict the spillover.**

	Inertial Hold # 1 (IH1)				Inertial Hold # 2 (IH2)							
Channel	Tb-earth	TA-upside down	Tcs'	η	Tb-earth	TA-upside down	Tcs'	η	Average of IH1 and IH2 (η_{IH})	Cal Data book F (η_F)	Proposed Cal Data Book G (η_G)	ΔTb over ocean
10V	126.2	8.6	2.74	0.95252	124.2	8.3	2.74	0.95389	0.95320	0.94435		1.6
10H	126.2	8.4	2.74	0.95412	124.2	8.1	2.74	0.95566	0.95489	0.94369		1.1
18V	150.7	10.0	2.75	0.95103	142.3	9.1	2.75	0.95465	0.95284	0.93968		2.6
18H	150.7	10.0	2.75	0.95122	142.3	9.1	2.75	0.95478	0.95300	0.94082		1.6
23V	181.9	8.8	2.77	0.96652	155.1	7.7	2.77	0.96743	0.96697	0.96601		0.2
36V	171.0	3.6	2.82	0.99517	168.8	3.6	2.82	0.99551	0.99534	0.99590		-0.1
36H	171.0	3.7	2.82	0.99492	168.8	3.6	2.82	0.99505	0.99499	0.99590		-0.1
89V	234.5	3.9	3.27	0.99742	214.4	3.8	3.27	0.99761	0.99751	0.99810		-0.2
89H	234.5	3.9	3.27	0.99717	214.4	3.9	3.27	0.99705	0.99711	0.99810		-0.2
166V	279.8	7.3	4.43	0.98969	250.3	7.2	4.43	0.98857	0.98913	1.00000	0.9891*	-2.9
166H	279.8	7.2	4.43	0.99003	250.3	7.4	4.43	0.98805	0.98904	1.00000	0.9891*	-2.9
183VA	264.5	6.6	4.76	0.99276	255.0	6.4	4.76	0.99344	0.99310	1.00000	0.9928*	-1.8
183VB	274.2	6.7	4.76	0.99266	259.2	6.7	4.76	0.99222	0.99244	1.00000	0.9928*	-2.0

* Average of the two channels of the same frequency

Conclusions

- **The current antenna pattern correction does not correct for spillover in the 166 and 183 GHz channels**
- **The two inertial holds both demonstrate that there is significant spillover from the 166 and 183 GHz channels.**
- **By not correcting the spillover, the 166 and 183 GHz channels are biased low by about 1.8 to 3K.**
- **We propose to update the GMI calibration algorithm with the spill-over correction presented in this document for 166 GHz and 183 GHz.**